CHAPTER 4

HVAC EQUIPMENT

4-1. General

a. Conventional, commercially available HVAC equipment is general adaptable to use in hardened ,. facilities whether aboveground or underground. The equipment reviewed in this chapter is well known to the experienced designers. The comments included are therefore mostly limited to potential areas of application with suggested solutions to the design considerations of chapter 2.

b. In a typical system, fresh air is drawn via a tunnel or shaft through an air filter of the conventional type and a CB filter; then it is drawn through a tempering coil. If close control of humidity is required in temperate and aired areas, the air will be passed through an air washer *or* sprayed coil during the summer months. In most cases, such high maintenance devices are not necessary since cooling coils are sufficient for summer dehumidification and duct-type steam humidifiers for winter humidification.

c. The conditioned outside air is ducted to various rooms or zones where zone air handling units or built-up units containing heating and cooling coils, filter, and fans will ingest, mix and condition the fresh and return air prior to distribution to the conditioned spaces. Special purpose areas with low humidity and wide temperature range requirements, such as storage areas for machinery, may be conditioned with chemical or mechanical dehumidifiers.

4-2. Air cleaners.

a. Criteria. The criteria for air cleaners in a hardened facility will address the removal of airborne contaminants from outside air brought in for air breathing equipment, environmental air within the structure, and outside air brought in for human consumption. Each requirement is unique in that the contaminant characteristics and the required filter efficiencies vary for each application.

b. Air washers. Air washers are used primarily in industrial air-conditioning. A central station air washer is bulky and requires more space than conventional coils and chiller. For this reason, an air washer will not be cost effective if installed in hardened facilities which require excavation of rock. Air washer design is covered in ASHRAE Handbook, Equipment.

c. *Dust separators.* Dust separators will be utilized to remove normal airborne contaminants during standby operation. Usage under other circumstances is not recommended due to decontamination and disposal problems.

d. Air filters. ,

(1) Industrial ventilation will generally require only removal of the coarser air dust particles. Administrative areas and areas, containing equipment sensitive to dust buildup will require removal of the smaller components of atmospheric dust. Cost, space, pressure drop, and effectiveness determine filter and filter media selection. Electronic air cleaners or high efficiency dry filters will be used for small particle removal. For critical installation, such as deep buried facilities, redundant high efficiency filter banks will be provided with provisions to keep one filter bank on stream while the other is being serviced.

(2) To increase the useful life of the high efficiency filters, prefilters will be installed particularly in areas of high dust concentration. Prefilters will also be installed upstream of the tempering coils to eliminate dust buildup downstream. At rated flow, the pressure drop will not exceed 0.3 in. wg when the unit is clean. Special electrostatic or other types of self-cleaning filters are not recommended; conventional disposable units are preferred. Prefilter installation will permit easy removal and replacement of the prefilters without undue leakage. Filters having a 90 percent efficiency for the removal of 50-micron particles will suffice if fallout protection is the only consideration.

(3) Automatic filters of the moving-curtain or replenishable-media-type will be used for remote installations because of the small amount of attention they require. This type of filter will also be used as a prefilter or medium efficiency filter to save space, or for large airflows. For medium and high efficiency requirements replaceable cells of the dry media type will otherwise be used. Typical performances are summarized in table 4-1. Air filters are also covered in the ASHRAE Handbook, Equipment.

e. Air purifiers. Air purifiers will be installed on the return air system in hardened facilities to remove tobacco smoke and objectionable odors from areas such as toilets and kitchens when the facility is in a button-up condition. Normal odor control is by dilution of return air with fresh air. Activated carbon filters are normally installed in a bypass section of the return air ducts and are activated by means of motorized dampers when the button-up signal is received. The commercial carbon filters normally used in this application are not suitable for CB service because they do no contain carbon specifically treated to sorbe CB agents.

TABLE 4-1

Performance of Dry Media Particulate Filters

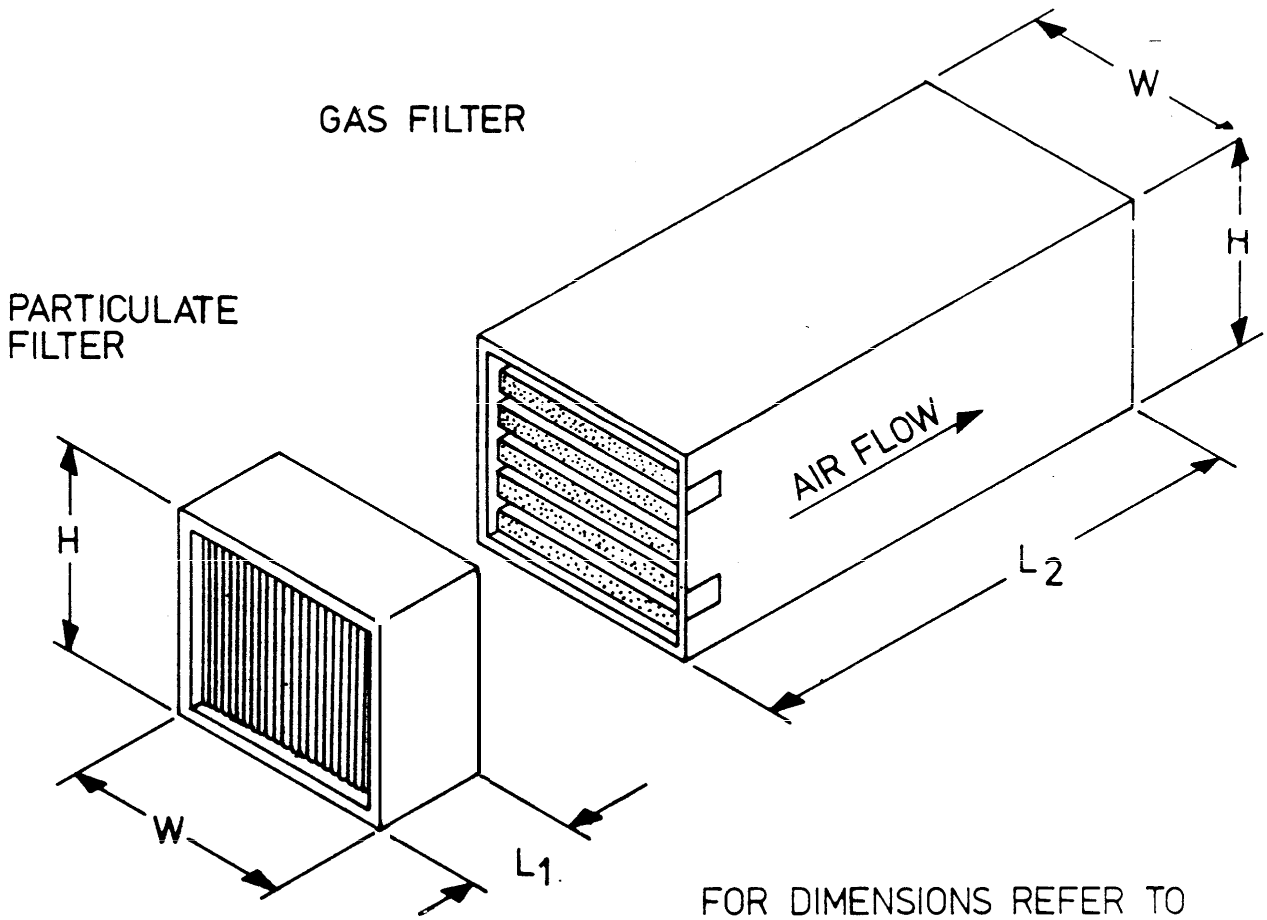
Parameter	Classification		
	Medium	High	Extreme
o Efficiency range, percent			
Typical atmospheric dust	40-75	80-99	100
0.3 micron particles	10-40	45-95	99.95
1.0 micron particles	40-70	75-99	99.99
5.0 micron particles	85-95	99.90	100
10 micron particles	98.99	99.99	100
o Pressure drop, in. wg			
minimum clean	.10	.20	1.0
minimum loaded	.25	.50	2.0
maximum clean	.25	.45	1.5
maximum loaded	.50	.99	3.0
o Dust capacity, lb/1000 cfm			
minimum	1	1	2
maximum	2	5	10
o Face velocity, fpm			
minimum	250	250	150
maximum	625	625	300

4-3. CBR filters.

a. CBR filters are required in hardened structures to exclude DBR agents and particles from the conditioned spaces. The portion of outside air to be filtered at all times through CBR filters depends the requirements of the occupied areas that must be protected within the facility. This protection must be continuous and no CBR filter bypass will be allowed.

b. For installation in a permanent -type structure having air-conditioning or a simple recirculation system, specific filters will be procured instead of complete filter units with motor blowers to permit a more flexible and uniform design of the air-handling equipment, particularly when multiple filter units are required. Table 2-4 and 2-5 and figures 4-1, 4-2, and 4-3 describe these filters and their assembly in a typical package. The FFU-17/E, C22R1, or C32R1 gas filters and the M20 particulate filter are recommended. These sizes can be handled more easily by maintenance personnel.

c. Extra care must be taken to ensure good sealing of leaks at the entrance and exit ends of the filter. Special maintenance and testing requirement will be as required by AMCCOM.

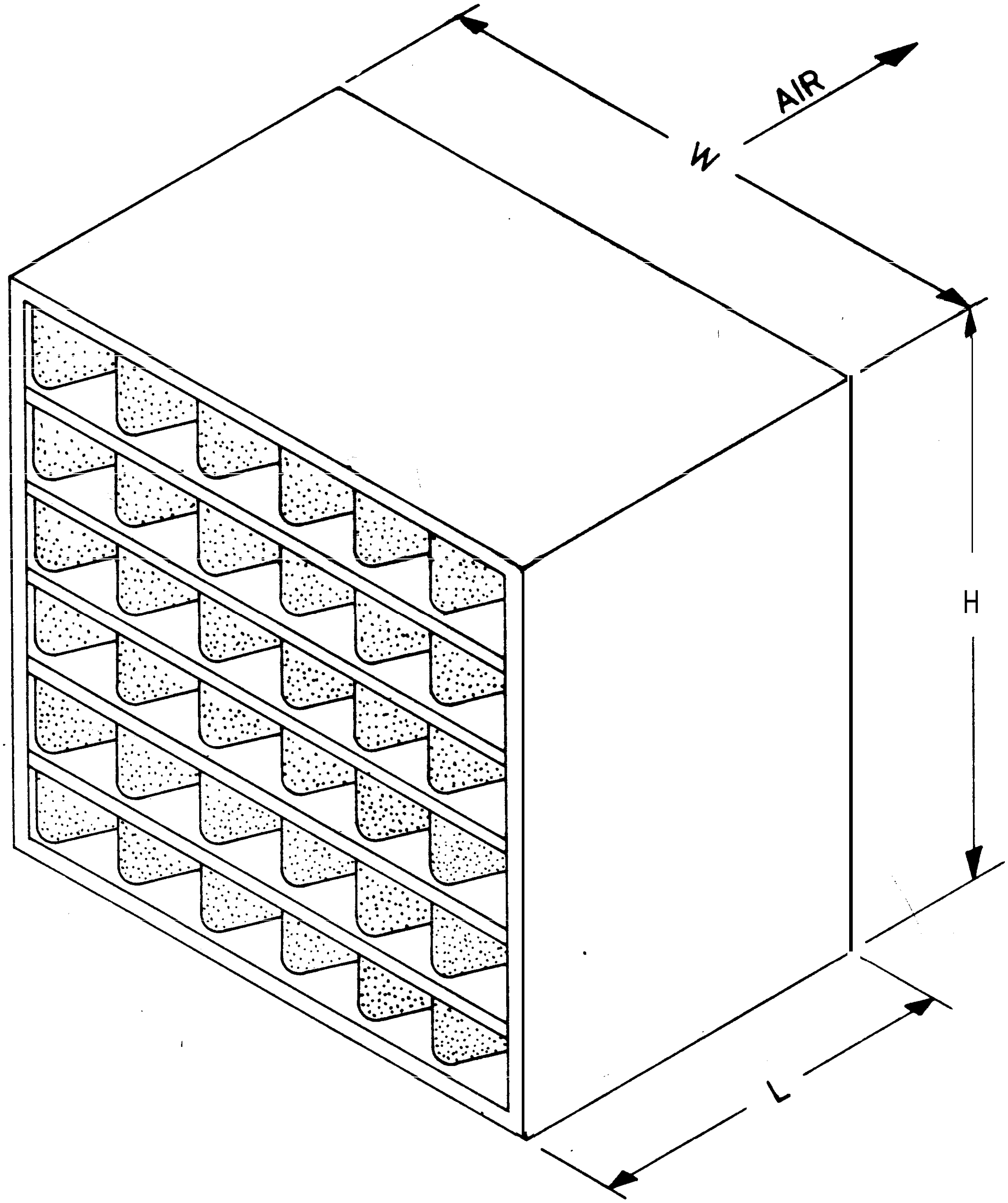


FOR DIMENSIONS REFER TO TABLES 2-4 AND 2-5.

USE GASKETS AS REQUIRED BETWEEN ELEMENTS FOR GASTIGHT ASSEMBLY.

U.S. ARMY CORPS OF ENGINEERS

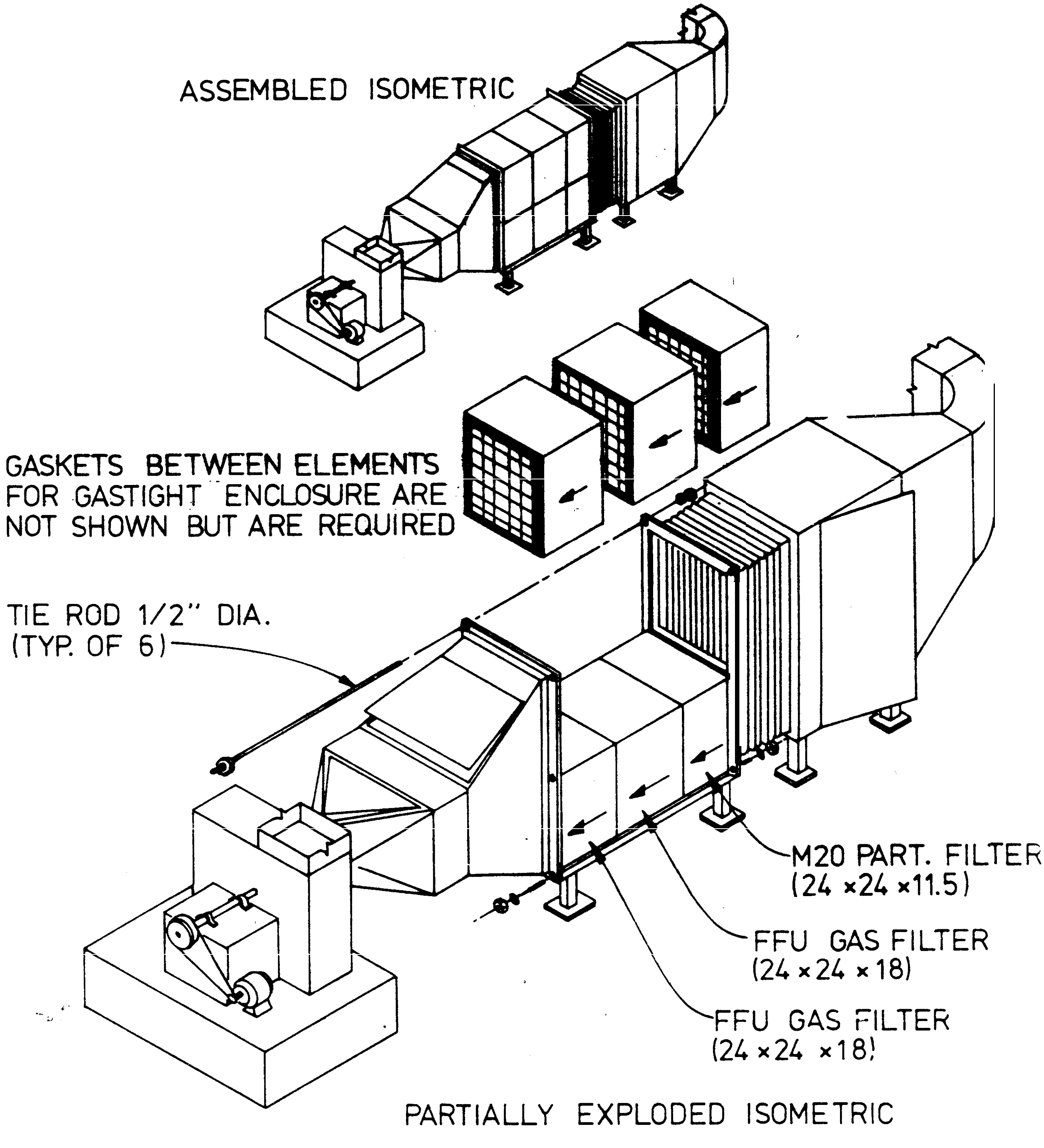
Figure 4-1. CB particulate and gas filter.



FOR DIMENSIONS REFER TO TABLE 2-5.

U.S. ARMY CORPS OF ENGINEERS

Figure 4.2. CB gas filter model FFU-17/E.



U.S. ARMY CORPS OF ENGINEERS

Figure 4-3. CB filter assembly.

4-4. Coils and piping.

a. Tempering coils.

(1) Tempering coils are normally installed in makeup air units. The tempering coils is used to heat the outside air in winter to prevent condensation on ducts and to prevent freeze-up of heating and cooling coils in downstream air handling units.

(2) Steam tempering coils require careful design to prevent freeze up of the coil. Design considerations will include large tubes of the steam distributing type, mounted vertically, with full steam pressure on the coils at all times. Face and bypass dampers controlled by a downstream duct-mounted thermostat, will be used for controlling the tempered air temperature. Controlling temperature with a modulating steam valve is not acceptable because of the danger of freeze-up.

(3) Hot water tempering coils, utilizing a heat exchanger to maintain water temperature, a coil pump to maintain flow, and thermostatically controlled face and bypass dampers can function successfully in extreme weather with proper controls and alarms. A mixture of water and antifreeze will be circulated through the coils to minimize the possibility of coil freeze-up should the controls or pump fail. The coil and the heat exchanger will be sized including the derating due to the added antifreeze component.

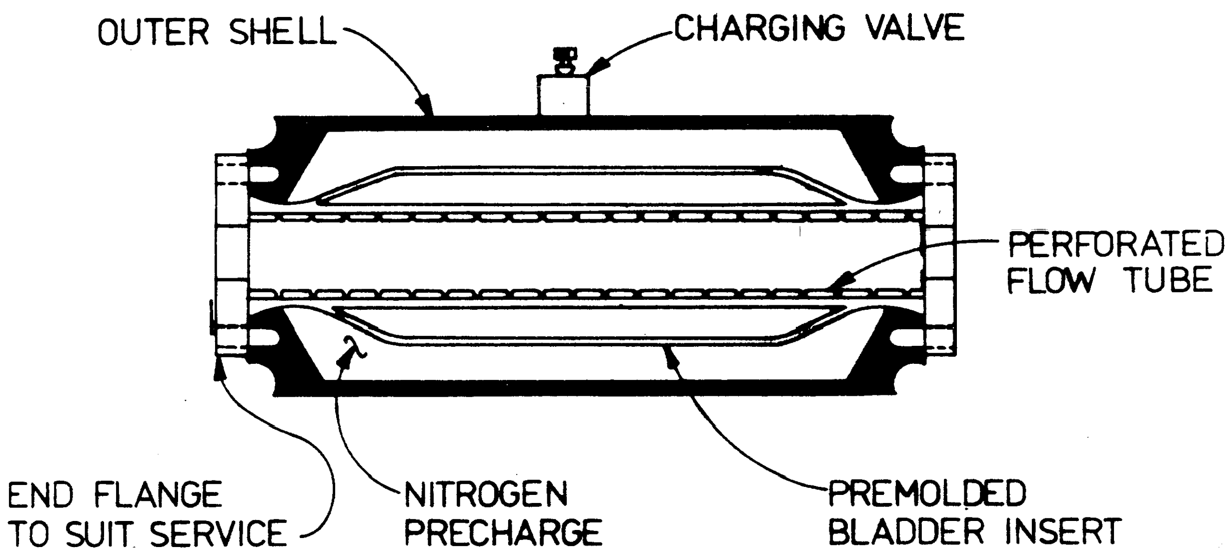
b. Air heating and cooling coils.

(1) Each hardened structure will be zoned and provided with at least one or more air-handling units for cooling and dehumidification. For underground facilities under conversion, the primary problem is one of dehumidification and reheat. During holding, the dehumidification load decreased, but the cooling load increases. Both the cooling and the reheat coils will therefore be provided in two sections. For cooling and dehumidification, one six-row section and one four-row section will be used, while for reheat a four-row section and a two-row section will be selected. In this way the air-handling units can meet the unusual load requirements for either dehumidification or cooling.

(2) Use of chilled water in unit-air-conditioners for individual rooms or zones has the advantage of simplicity and flexibility of control. Chilled-water lines that pass through spaces with high dewpoints or which are air-conditioned will be insulated to prevent condensation. Temperature control will be accomplished by starting and stopping the fans in the units, by means of dampers to control the airflow through the cooling coils, by regulating the flow or temperature of chilled water to the coils, or by a combination of these methods. Heating coils will be installed in the air-conditioning units along with the cooling coils, if desired.

(3) For central chilled water system and when. cooling is critical to the mission of the facility, a loop-type system of chilled water distribution will be provided with necessary valving to isolate loop segments in case of failure of a portion of the system.

c. Piping. The design of all piping systems and materials used in a hardened facility will conform with nationally recognized codes, standards, manuals, and recommended practices. Flexible connectors, vibration eliminators, and expansion joints will be utilized to connect piping to HVAC equipment which is subject to movement. Piping passing to and from RFI exclusion or containment areas will be designed to preclude transmission of the RFI waves. Hydraulic transient pressures are covered in TM 5-858-5. In-line-flow-through attenuators of the precharge-bladder-type are available in a wide range of sizes and pressures. Figure 4-4 shows the construction features of a typical flow-through, hydropneumatic, bladder-type attenuator.



U.S. ARMY CORPS OF ENGINEERS

Figure 4-4. Bladder-type attenuator for chilled water.

4-5. Refrigeration equipment.

a. The refrigeration cycle can be used for both cooling and dehumidification by absorbing heat at the evaporator and for heating by rejecting heat at the condenser. A chilled-water system is preferable for underground installation because breaks or leaks in the distribution lines will not create a critical condition within the structure, either from the standpoint of the replacement of the coolant or the generation of potentially dangerous gases.

b. Provision will be made for at least one or more water chiller units complete with motor, compressor, condenser, and evaporator for each structural unit to be conditioned. Refrigerant compressors of the reciprocating type will have three stages of capacity reduction. Centrifugal type units will have a capacity control system providing for continuously variable capacities of from 10 to 100 percent. Absorption type units will have automatic steam generation and control Water chiller units of the same type will be interconnected to ensure maximum utilization of capacity control.

c. If the supply of condenser water is drawn from underground wells or reservoirs, the chemical content of this water must be analyzed to determine the fouling factor which must be considered in the condenser design and in determining the requirement for water treatment equipment in the system.

4-6. Fans.

a. Underground facility design requires a powered air moving device such as a fan for ventilation and exhaust. Standard fan designs are available for most fan requirements. Heavy-duty ventilating fans will be used for more severe conditions.

(1) Fan type selection depends on application. When space is not a factor centrifugal fans will backwardly curved and air foil shaped blades will be used for maximum efficiency. Vaneaxial fans are used when space is at a premium and nonturbulent inlet conditions can be obtained. The use of inlet vane straightness for this purpose is recommended. Propeller fans are generally limited to applications requiring 2 in. wg will be mounted on inertia blocks.

(2) In selecting the proper fan, consideration will be given to airflow, head pressure, noise, and available space. In the majority of protective structures, space will govern fan selection. However, space must be balanced against noise and efficiency of operation.

b. In selecting the proper fan, consideration will be given to airflow, head pressure, noise, and available space. In the majority of protective structures, space will govern fan selection. However, space must be balanced against noise and efficiency of operation.

(1) Head pressure requirements will be determined carefully, particularly with regard to seasonal variations of the air temperature, CB filters and such other items as blast-closure valves, prefilters, and structure pressurization. Because of the high efficiency of the CB filter, it is recommended that the higher resistance of 6 in. wg be used in determining fan capacities:

(2) Noise is of major importance in a closely occupied structure. Therefore, duct work and fan mounts will be carefully designed. Ducts will be connected to fan and filter inlets and outlets by means of butyl rubber or butyl coated nylon cloth material. Main supply fans will be remote from occupied areas and provided with resilient sound-absorbing bases. Noises due to high-velocity ducts, abrupt turns, and rigid connections to fans will all be considered. Where high-velocity minimum-size equipment must be used, an adequate acoustical and vibration treatment will be employed.

(3) ASHRAE Handbook, Equipment, will be consulted for fan sizing, selection, application, and control. Parallel start and operation of fans will be done in accordance with fan manufacturer's recommendation in particular when using pitch controlled vaneaxial fans.

4-7. Duct systems.

a. Ducts which may carry contaminated air or run through areas which may become contaminated will be gastight. Duct systems will be designed within prescribed limits of available space, friction loss, noise level, heat loss or gain, and pressure containment. Both high velocity and low velocity duct systems will be designed in accordance with ASHRAE Handbook Fundamentals. The aspect ratio R of rectangular ducts defined as the ratio of the longer to the shorter side of the cross-section is an important parameter in the optimization of duct systems.

b. The economic factors of first cost and operating cost will be evaluated in conjunction with available space to determine the best duct system. Each application is different and will be analyzed separately. Normally square or round ducts will be preferred to rectangular ducts of larger aspect ratio because they are less subject to heat pick up and more economical as shown below.

(1) L feet downstream the temperature pickup ($T_L - T_1$) of V' cfm of air flowing in a duct of aspect ration R (use R = 0 if round), conductance U in Btuh/ft^2 °F (use U = 1 if uninsulated and 0.5 if furred in), cross section S in ft^2, exposed to a space temperature T_a is approximately

$$(T_L - T_1) = (T_a - T_1)(LUS^{.25})[1 + (R/10)](5V')^{-.68} \qquad \text{(eq 4-1)}$$

(2) The installed cost of a round duct of same cross-section is less than 70 percent of the corresponding square duct. For rectangular ducts of aspect ratio R, the incremental first cost fractions (I_1) and operating cost fraction (I_0), relative to a square duct at the same airflow, are given respectively by equation 4-2 and equation 4-3.

$$I_1 = .125\,(R\text{-}1) \qquad \text{(eq 4-2)}$$

$$I_0 = .0008\,(R\text{-}1)^2 \qquad \text{(eq 4-3)}$$

c. A low-velocity duct system using rectangular ductwork is practical in hardened industrial facilities where space is of secondary importance. Fan horsepower increases approximately as the square of the velocity and noise generation increases with the velocity; therefore, the velocity will be kept low for quiet and economical operation. Standard ducts will be constructed in accordance with Sheet Metal and Air Conditioning Contractor's National Association (SMACNA) Duct Construction Standards.

d. A high-velocity duct system is often most practical in a facility where space is at a premium. High-velocity systems have velocities in excess of 2,000 fpm and from 6 to 10 in. wg static pressures. The design of a high-velocity system involves a compromise between reduced duct sizes and higher fan horsepower. The reduced duct size and space requirements cut initial excavation costs but increased fan power means higher operating costs. High-velocity ducts can be used anywhere in an air-conditioning system as long as means are provided to control flow and attenuate sound at the air outlets. Ducts will be constructed in accordance with SMACNA Duct Construction Standards.

4-8. Humidity control systems.

a. Criteria. The selection and application of humidification and dehumidification equipment involves the evaluation and consideration of both the environmental criteria for the occupancy or process and the characteristics of the facility enclosure. These may not always be compatible in an underground structure and a compromise solution will be necessary.

b. Humidifiers.

(1) Process control and material storage humidity control conditions are usually specific and are related to the control of moisture, rate of chemical or biochemical reactions, rate of crystallization, product accuracy or uniformity, corrosion, and static electricity. Typical conditions of humidity for the storage of certain materials may be found in table 2-3.

(2) Industrial humidifiers for central air-handling systems usually incorporate a heated water pan or direct steam injection. Heated pan-type humidifiers offer a broad range of capacity and are heated by an electric element or steam or hot water coil. Controls and maintenance of humidifiers installed underground will conform to the standard practice for aboveground structures.

c. Dehumidifiers.

(1) Because of the difficulty of estimating accurately the total anticipated moisture loads, design of the moisture-removal systems will provide for two types of installation. A permanent system will be provided to handle loads imposed by the end-use requirements of the structure after the conversion period. A temporary or semi-permanent system will be provided to handle excess loads during conversion and to provide auxiliary capacities in case of breakdown.

(2) A mechanical dehumidifier consists of a refrigerating machine so arranged that air passes through a cooling coil and then through the condenser. The air, first cooled and dehumidified by the cooling coil, picks up the heat rejected by the condenser. In this process, moisture removed from the air by the cooling coil is drained away as' a liquid but the air is reheated by the heat equivalent of the power delivered to the machine. Machines of this type are very useful in spaces with considerable latent loads and in which moderate heating is either desireable or of no consequence. They have an advantage over chemical dehumidifiers in that the condensate is drained away as liquid through pipes, rather than exhausted as vapor in the air through ducts.

(3) The chemical-sorbent or dessicant-type dehumidifier is not ordinarily affected by temperature levels and will operate effectively over a wide range of temperatures. Solid dessicant units require only power hookups and exhaust outlets for discharging moisture vapors from the dessicant beds during the heating or regeneration cycle. Liquid dessicant-type equipment usually requires auxiliary steam for the treatment of the moisture-laden dessicant. Solid dessicant equipment generally returns more heat through the dried air stream to the occupied space than the liquid-dessicant-type. These and other equipment selection factors are covered in ASHRAE Handbook, Equipment.

4-9. Computer area cooling.

a. Criteria. Command centers, radar installations, missile launch facilities and similar areas will generally contain computers and ancillary equipment which are sensitive to extremes of temperature, humidity, and the presence of dust. The environmental criteria requirements for computers and for areas housing the machines will vary widely with the computer manufacturer and the computer cooling configuration.

b. Air-cooled computers.

(1) Air-cooled units will have either cooling air drawn from the room and circulated through the unit by an internal fan; air forced through the unit by fans from a remote central supply system; or self-contained computer room air-conditioner units within the computer room. The latter two systems utilize under-floor ducts or plenums to supply the computer units with cooling air. Vertical space is at a premium in underground facilities. This is reflected in the height of raised-floor plenums. Therefore, particular attention must be given to the following:

- Locating the computer room units preferably in center of room.
- Keeping cables and wire bundles from blocking the airflow.
- Large room underflow ducting for uniform air distribution.
- Controlling supply air dewpoint to prevent mildew and fungus.

(2) Remote central air supply systems will multiple fans for reliability are more adaptable for hardened facilities than unitary units. The requirements for complete redundant unitary units for reliability and the necessity of routing condenser water lines in the computer room for unitary units will influence the computer air-cooling system selection to favor a remote central air supply system. The necessity of repairing the unitary equipment in the computer area is an additional detriment.

(3) The ASHRAE Handbook, Applications lists the typical design conditions for computer room cooling systems; however, the equipment manufacturers' requirements will govern.

c. Water-cooled computer equipment.

(1) Some computer equipment on the market requires cooling water to remove a portion or all of the heat generated within the cabinets. The cooling water system configuration within the cabinets will vary, but in almost all cases, the cooling media circulating within the cabinets will be distilled or demineralized water. Computers may be furnished with integral closed-loop. cooling systems made up of water to water heat exchanger and pump, or the demineralized water may be pumped to the computer cabinets from central demineralized water/ chilled water heat exchangers.

(2) Some computer systems are cooled by circulating demineralized water from a central system through electronic racks at pressure below atmospheric pressure. The system is designed to ingest air into the cooling water circuits, should a leak occur, in lieu of leaking water onto the rack electronic components, as would be the case with a system operating at a positive pressure.

(3) Leak detection devices should be installed in the plenum beneath the computer floor to warn of leaks in the cooling water lines. All critical functions such as water flow, pressure, and temperature should be monitored locally and remotely for each computer cabinet.

4-10. Boilers and heat recovery.

a. The requirement for supplemental heating will be greatest when the facility is on standby. The major requirements for heating during normal operation will be heating fresh air to interior design conditions and for reheating.

(1) The greatest liabilities of combustion type boilers are space, combustion air, and flue gas requirements, which eliminate them from consideration for underground service. For aboveground facilities, fuel and ash handling requirements and the necessity to shut the boiler down and button-up on short notice render coal-fired boilers unsuitable but oil fired package boilers are acceptable for aboveground service.

(2) In industrial facilities where process steam is required, medium or high pressure steam boilers are recommended. Electrically-heated steam boilers are well suited for hardened facilities having a large demand for humidification steam in the wintertime.

b. As a rule, where diesel-engine jacket water waste heat is recovered in conjunction with waste heat recovery from the exhaust gases, a hot water boiler is the logical choice. It is estimated that heat recovery mufflers on the exhaust stack and jacket water heat exchangers can recover 20 to 30 percent of the input fuel energy which is rejected in exhaust gasses and jacket water. The recovered energy can be transferred to a hot water or low pressure steam system to heat domestic hot water and the facility. The quantity of low pressure steam powered by flash vaporization of the jacket water is equal to the heat recovered divided by the difference between the steam enthalpy and the enthalpy of the feedwater returned to the flash tank.

c. The combustion gas exhaust temperature must be kept above its acid dewpoint to prevent corrosion of surfaces in contact with it. Unless the fuel contains no sulfur, a 300 °F acid dewpoint is usually assumed. Diesel engine jacket water design will not exceed 2500 F, 45 psi, and 150 F temperature rise to minimize thermal stresses on the engine. To avoid leaks and over pressure, the primary circulation loop of the jacket water will be limited to local heat exchangers to transfer the salvaged heat to separate secondary heating circuits. Another 5 percent of the total fuel input energy may be recovered from the lube oil system, but at lower temperature levels than the water jacket since the lube oil operating temperature cannot presently exceed 200 °F while maintaining reasonable lube oil life.